

Digital Empowerment and Urban–Rural Common Prosperity: Income Convergence Mechanisms Under the Threshold of Circulation Industry Development

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Abstract: Based on panel data from 29 Chinese provinces spanning the period 2004 to 2019, this study employs principal component analysis to measure the level of digital economy development. Utilizing fixed effects models, mediation effect models, and threshold models, it investigates the impact of the digital economy on the urban-rural income gap from the perspective of the circulation industry. The findings indicate that the digital economy plays a significant role in narrowing the urban-rural income gap, with a more pronounced income-enhancing effect on rural residents. The circulation industry is identified as a critical transmission channel through which the digital economy influences the income gap. Furthermore, the effect of the digital economy intensifies with the advancement of the circulation industry, exhibiting nonlinear characteristics. This paper elucidates the bridging role of the circulation industry in the income distribution effects of the digital economy, providing policy references for promoting urban-rural common prosperity.

Keywords: Digital Economy; Urban-Rural Income Gap; Circulation Industry; Mediation Effect; Threshold Effect

I. Research Background and Problem Statement

1.1 Policy Orientation of Digital China Construction and Integrated Urban-Rural Development

In recent years, the scale of China's digital economy has expanded persistently, surpassing 50 trillion yuan by 2023 and accounting for over 40% of GDP¹, thereby establishing itself as a pivotal engine of economic

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growth. Concurrently, the urban-rural income gap remains a salient issue. Although the income growth rate of rural residents has outpaced that of their urban counterparts for several consecutive years, the absolute disparity continues to widen. These two seemingly parallel trajectories imply a profound underlying interconnection, prompting a critical inquiry: does the burgeoning digital economy serve to bridge the urban-rural divide, or does it inadvertently engender new chasms?

From a policy perspective, the national strategic positioning of the digital economy has evolved from an "emerging industry" to a "critical force" and ultimately to a "national strategy." The report to the 20th National Congress of the Communist Party of China explicitly advocated accelerating the construction of a Digital China, juxtaposing this objective with strategies for rural revitalization and regional coordinated development. However, in practical implementation, the diffusion of digital technologies often follows a path characterized by "urban priority, rural follow-up." Cities, leveraging advantages in infrastructure, talent pools, and industrial agglomeration, take the lead in digital transformation. Conversely, vast rural areas, particularly those in remote mountainous regions, continue to grapple with challenges related to network coverage, logistics accessibility, and talent attraction. This uneven pace of digital advancement inherently imbues the distribution of digital economy dividends with an "urban bias."

Observations from reality reveal intriguing phenomena. On one hand, live-streaming e-commerce has enabled numerous agricultural products to access broader markets, with farmers in "Taobao villages" experiencing income doubling, demonstrating the potential of digital technologies to enhance rural prosperity. On the other hand, the urban-rural gap in smartphone penetration persists at over 20 percentage points, and the difficulties encountered by left-behind elderly rural residents when navigating health codes or online services reflect a contrasting reality. This suggests that the popularization of digital technology does not automatically translate into the equitable sharing of digital dividends, and the coverage of digital infrastructure does not guarantee the acquisition of digital capabilities. As the "access divide" gradually narrows, the "skills divide" and "application divide" are emerging as new fault lines.

Academic discourse on this issue remains far from consensus. Optimists posit that digital technology possesses inherently inclusive attributes, capable of reducing information asymmetry, expanding market reach, and naturally benefiting disadvantaged groups. Pessimists, however, contend that technological diffusion adheres to the "Matthew effect," whereby first-mover advantages accumulate, ultimately exacerbating disparities^[1]. These contrasting perspectives, while seemingly contradictory, may each capture facets of reality – the crux lies in the specific stage of digitalization and the degree to which channels for transmitting digital dividends to rural areas are unobstructed.

Based on the foregoing observations, this paper focuses on three interrelated questions: First, is the impact of digital economy development on the urban-rural income gap linear or nonlinear? Does a critical threshold exist beyond which the direction of the effect reverses? Second, what role does the digital divide play in this process? Is it merely an impediment, or does it function as a structural variable exerting a moderating influence? Third, considering the network externalities inherent in the digital economy, does the digitalization process in one region generate spillover effects on neighboring areas, thereby influencing the broader spatial pattern of urban-rural income distribution?

1.2 Real-world Observations and Research Entry Point

This paper seeks to transcend two major limitations prevalent in existing research at the theoretical level. The first is the limitation of research perspective. Existing literature frequently adopts a unidimensional approach, focusing either on digital infrastructure or e-commerce applications, thereby failing to comprehensively capture the complex ramifications of the digital economy. This paper constructs a multi-dimensional evaluation system encompassing three dimensions – infrastructure, digital industrialization, and

industrial digitalization – striving for a more holistic characterization of digital economy development levels. The second limitation pertains to research methodology. The majority of studies presuppose linear relationships, employing conventional panel models for estimation, which may obscure the phased characteristics of the digital economy's impact^[2]. This paper introduces nonlinearity tests and threshold models, aiming to uncover the critical conditions governing directional shifts in the effect, thereby offering a novel perspective for understanding the "double-edged sword" nature of the digital economy.

The value of this study lies theoretically in providing more targeted references for policy formulation. Presently, various regions are promulgating digital village construction plans, investing substantial resources in deploying optical fiber cables, constructing base stations, and providing farmer training. However, what is the actual efficacy of these measures? Under what conditions are they most effective? Which regions warrant priority intervention? By analyzing the moderating effect of the digital divide and spatial spillover effects, this paper endeavors to address these specific questions pertinent to policy practice. Particularly, the findings concerning regional heterogeneity can provide empirical support for the principle of "adapting measures to local conditions," thereby averting a one-size-fits-all approach in policy design.

II. Theoretical Basis and Research Hypotheses

2.1 Theoretical Evolution of the Relationship between Digital Economy and Urban-Rural Income Gap

Regarding the manner in which the digital economy affects the urban-rural income gap, academic inquiry has undergone a transition from linear to nonlinear thinking. Early research, predominantly grounded in technology diffusion theory, posited that the spread of new technologies follows a trajectory of "cities first, villages later; developed areas first, underdeveloped areas later." Consequently, during the initial stages of diffusion, the urban-rural income gap inevitably widens; only after technological dividends have sufficiently permeated rural areas does the gap begin to contract. This logic implies a certain phased characteristic in the relationship between the digital economy and the urban-rural income gap, rather than a simple positive or negative correlation.

Scholars subsequently began to recognize that the distinctive attributes of the digital economy might alter this conventional paradigm. Unlike industrial technologies, digital technologies are characterized by low marginal costs, high permeability, and network externalities. Low marginal costs imply a substantially reduced threshold for rural areas to access digital services^[3]. High permeability enables digital technologies to transcend geographical barriers, directly reaching remote farmers. Network externalities entail that the value accruing to each participant increases with the size of the user base, potentially enabling late-developing regions to achieve leapfrogging effects. These characteristics suggest that the digital economy might benefit rural areas earlier and more directly than traditional technologies.

However, reality proves more complex. While the digital economy reduces information acquisition costs, it simultaneously imposes heightened demands on users' knowledge reserves, learning abilities, and application scenarios^[1]. Urban residents, leveraging educational advantages and access to diverse application scenarios, can more readily convert digital tools into income-generating opportunities. Rural residents, conversely, may be excluded from digital dividends due to skill deficiencies. This disparity in "digital capability" complicates the income distribution effects of the digital economy. Some scholars have encapsulated this as the coexistence of "digital dividends" and the "digital divide": technology itself is neutral, but the societal context of its implementation determines the flow of its benefits.

Based on the preceding discussion, a question warranting in-depth exploration is whether the impact of the digital economy on the urban-rural income gap exhibits nonlinear characteristics, specifically the possibility of a directional shift as digitalization levels increase. Several studies have already broached this issue. Research by

Cheng Mingwang et al., for instance, found that the impact of internet penetration on the urban-rural income gap is subject to a threshold effect: when penetration falls below a certain level, the internet widens the gap; above that level, it narrows the gap. This finding provides preliminary evidence for nonlinearity, but its generalizability remains contingent upon further testing due to limitations in data periods and variable selection.

2.2 Moderating Role of the Digital Divide

When discussing the mechanism through which the digital economy affects the urban-rural income gap, the digital divide is an unavoidable variable. The digital divide refers to the gap between different groups in accessing, utilizing, and benefiting from digital technology. Early research primarily focused on the "access divide," i.e., hardware-level differences such as computer ownership and internet connectivity. As network coverage has increased, the access divide has gradually narrowed, but issues pertaining to the "skills divide" and "application divide" have come to the fore.

The skills divide manifests in rural residents' proficiency with digital tools. Even with smartphone access, if usage is confined to entertainment and social networking, and does not extend to productive activities such as information acquisition, online transactions, or e-learning, the income-enhancing potential of digital technology remains unrealized. The application divide is more subtle, manifesting as differences in the urban-rural digital ecosystem – cities boast abundant online services, convenient payment systems, and comprehensive logistics networks, whereas rural areas may have only scattered service points, unstable network signals, and high logistics costs. This ecological disparity significantly attenuates the effectiveness of the same digital technologies when deployed in rural settings.

The digital divide not only directly affects rural residents' income levels but may also moderate the overall effect of the digital economy. In regions characterized by a large digital divide, digital economy dividends are more readily intercepted by urban areas, with rural areas receiving only limited spillovers. In regions with a small digital divide, rural residents can access digital services contemporaneously with urban residents, allowing the inclusive effect of the digital economy to materialize fully. This implies that the digital divide is a key variable for understanding the income distribution effects of the digital economy; neglecting its moderating role could lead to mischaracterizations of the overall effect.

2.3 Introduction of the Spatial Spillover Perspective

A salient characteristic of the digital economy is its capacity to transcend geographical boundaries. The cross-regional flow of information implies that the digitalization process in one region can generate spillover effects on neighboring areas. These spillovers can be positive, such as the diffusion of digital technologies from central cities to surrounding rural areas, e-commerce platforms driving regional agricultural product sales, or digital financial services covering adjacent counties and townships. They can also be negative, manifested as resource concentration in central cities, talent siphoning, or marginalization of local industries.

The direction of the spatial spillover of the digital economy depends on the nature of inter-regional interactions. In areas characterized by close industrial linkages and interconnected infrastructure, spillover effects tend to be positive. In areas dominated by competition and unidirectional factor flows, siphoning effects may prevail. Given the considerable developmental disparities among China's eastern, central, and western regions, eastern urban agglomerations, having established relatively mature digital ecosystems, may generate positive drivers for their peripheries. Central and western urban agglomerations, still in the stage of factor agglomeration, may exhibit more pronounced siphoning effects on surrounding rural areas.

Introducing this perspective helps overcome the limitation of traditional research, which often focuses solely on local conditions. Changes in the urban-rural income gap depend not only on local capitalization levels

but also are potentially contingent upon the capitalization construction of surrounding areas. Ignoring spatial correlation could lead to overestimation or underestimation of the digital economy's effect. For example, a rural area might have low capitalization itself, but if neighboring cities are digitally advanced, radiation effects could still boost local income. Conversely, if a region invests heavily in its own capitalization but surrounding areas are siphoning resources, the effect might be considerably diminished.

2.4 Formulation of Research Hypotheses

Synthesizing the foregoing theoretical analysis, this paper proposes three research hypotheses for empirical testing.

Regarding the directional impact of the digital economy, based on the phased patterns of technological diffusion and the clues from existing empirical studies, this paper argues that there is likely to be a certain non-linear relationship between the digital economy and the urban-rural income gap. At lower levels of capitalization, cities benefit first, and the urban-rural income gap tends to widen. Once capitalization surpasses a certain critical point, rural areas begin to catch up, and the gap tends to narrow^[4]. Accordingly, Hypothesis 1 is proposed: There exists an "inverted U-shaped" relationship between the level of digital economy development and the urban-rural income gap, meaning the gap first widens and subsequently narrows as capitalization levels increase.

Regarding the mechanism of the digital divide, considering that disparities in digital skills and application scenarios may constrain rural residents' ability to partake in digital dividends, this paper posits that the digital divide plays a moderating role in the relationship between the digital economy and the urban-rural income gap. When the digital divide is substantial, the digital economy is more likely to widen the urban-rural gap. When the digital divide is minimal, the digital economy is more conducive to narrowing the gap. Accordingly, Hypothesis 2 is proposed: The digital divide positively moderates the impact of the digital economy on the urban-rural income gap. That is, the larger the digital divide, the stronger the effect of the digital economy in widening the gap, or the weaker its effect in narrowing the gap.

Concerning spatial spillover effects, and based on the network externalization and regional associations of the digital economy, this paper posits that the development of the digital economy not only affects the local urban-rural income gap but also generates spillovers to neighboring areas. In regions with strong regional coordination, these spillovers manifest as positive drivers. In regions dominated by competition, they may manifest as siphoning effects. Accordingly, Hypothesis 3 is proposed: The development of the digital economy exhibits significant spatial spillover effects, and the direction of these spillovers demonstrates regional heterogeneity.

III. Research Design and Methodology

3.1 Data Sources and Sample Selection

This paper selects the panel data of 31 provinces, autonomous regions, and municipalities directly under the Central Government in China from 2011 to 2022 as the research sample. The selection of this time period is mainly based on the following considerations. The year 2011 marked the starting point of the full popularization of mobile Internet in China. Smartphones began to enter ordinary households on a large scale, and new business forms such as mobile payment, social e-commerce, and short videos emerged one after another. Digital economy started to deeply embed in residents' daily lives. Before 2011, the scale of digital economy was limited and its form was single, so its impact on the urban-rural income gap was not significant; after 2011, digital technology accelerated its penetration, and its socio-economic effects gradually emerged. Taking 2011 as the

starting point of the research can not only ensure the availability of data, but also more accurately capture the substantive impact of digital economy on urban-rural relations.

In terms of data sources, this paper mainly relies on the annual statistical data released by the official website of the National Bureau of Statistics, the Operation Monitoring and Coordination Bureau of the Ministry of Industry and Information Technology, and the China Internet Network Information Center (CNNIC), supplemented by authoritative publications such as the *China Statistical Yearbook*, *China Rural Statistical Yearbook*, and *White Paper on China's Digital Economy Development*. For the missing data of individual provinces in some years, linear interpolation method is adopted for supplementation to ensure the balance of panel data. It should be noted that due to the adjustment of statistical caliber, individual indicators fluctuate in individual years, and this paper has carefully checked this during data processing to ensure the consistency and comparability of data.

3.2 Variable Definition and Measurement

For the explained variable – measuring the economic disparity between urban and rural areas – we construct the primary indicator using the ratio of urban residents' average disposable income to rural residents' average disposable income^[5]. This indicator directly reveals the comparative relationship between urban and rural income levels, facilitates cross-date analysis and comprehension of policy implications, and is therefore widely employed in numerous related research endeavors. Additionally, to mitigate potential estimation errors arising from a single indicator, we incorporate the Theil index as an alternative measure during robustness checks to enhance the accuracy and reliability of the findings. The advantage of the Theil index lies in its capacity to reflect the structural characteristics of income distribution, exhibiting higher sensitivity to changes in the income of low-income groups.

This paper constructs a comprehensive evaluation index system to measure the level of digital economy development, focusing on three core aspects: digital infrastructure, digital industrialization, and industrial capitalization^[6]. For the digital infrastructure dimension, three indicators are selected: mobile phone penetration rate, number of internet broadband access ports, and length of optical cable lines, reflecting the level of hardware support for digital technology in each region. For the digital industrialization dimension, three indicators are selected: software business revenue, added value of the electronic information manufacturing industry, and total telecommunications business volume, measuring the scale of the industry constituted by digital technology itself. For the industrial capitalization dimension, three indicators are selected: e-commerce transaction volume^[7], enterprise information application rate, and number of rural e-commerce service outlets, describing the depth of integration between traditional industries and digital technology. For weight determination, the entropy method is employed for objective weighting to avoid subjective interference, ultimately synthesizing these into a digital economy development index for each province.

Regarding the moderating variable – the measurement of the digital divide – this paper measures it from two dimensions: the access divide and the skills divide. The access divide is represented by the differential in internet penetration rates between urban and rural areas; a larger differential indicates a greater gap for rural areas at the access level. Measuring the skills divide is comparatively complex. This paper utilizes the ratio of the average years of education of rural residents to that of urban residents as a baseline indicator, supplemented by indicators such as the usage rate of mobile payments in rural areas and the proportion of rural residents engaging in online shopping for comprehensive assessment. It should be noted that due to substantial variations in the availability of skills divide data across provinces, this paper primarily employs the education years ratio as a proxy variable in the main regression and attempts to introduce other indicators for verification during robustness checks.

Regarding control variables, this paper selects the following factors that may potentially influence the urban-rural income gap: Economic development level, represented by per capita gross regional product, adjusted for price factors [8]; Industrial structure, represented by the proportion of tertiary industry added value to regional GDP, reflecting the degree of economic structural transformation; Fiscal support for agriculture, represented by the proportion of expenditure on agriculture, forestry, and water affairs in total fiscal expenditure, measuring government support for rural development; Degree of openness, represented by the proportion of total imports and exports to regional GDP, examining the impact of external economic connections; Urbanization rate, represented by the proportion of the permanent urban population to the total population, controlling for the impact of changes in the urban-rural population distribution.

3.3 Empirical Model Specification

To test the nonlinear relationship between the digital economy and the urban-rural income gap, this paper first constructs a panel regression model incorporating a squared term. The model is specified as follows:

$$gap_{it} = \alpha_0 + \alpha_1 digital_{it} + \alpha_2 digital_{it}^2 + \beta X_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

Here, subscripts *i* and *t* represent province and year, respectively. *gap* denotes the urban-rural income gap, *digital* represents the digital economy development index, *digital*² is its square term, *X* is the vector of control variables, μ_i and δ_t represent province fixed effects and time fixed effects, respectively, and ε is the random error term. According to the theoretical analysis above, if α_1 is significantly positive and α_2 is significantly negative, it indicates an "inverted U-shaped" relationship between the digital economy and the urban-rural income gap, i.e., the gap first widens and subsequently narrows as digitalization levels increase.

To test the moderating role of the digital divide, this paper introduces an interaction term between the digital divide and the digital economy, constructing the moderation effect model as follows:

$$gap_{it} = \beta_0 + \beta_1 digital_{it} + \beta_2 divide_{it} + \beta_3 (digital_{it} \times divide_{it}) + \gamma X_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

Here, *divide* is the digital divide variable, and *digital* × *divide* is the interaction term between the digital economy and the digital divide. If the interaction term coefficient β_3 is significantly positive, it indicates that the digital divide positively moderates the impact of the digital economy on the urban-rural income gap, i.e., the larger the digital divide, the stronger the effect of the digital economy in widening the gap. If β_3 is significantly negative, it indicates negative moderation, i.e., the smaller the digital divide, the stronger the effect of the digital economy in narrowing the gap [9].

To investigate the spatial spillover effects of the digital economy, this study introduces spatial econometric models. The core of spatial econometric methods lies in reflecting the degree of correlation between regions through a spatial weight matrix. In this study, two types of spatial weight matrices are employed: The first is a geographic distance weight matrix constructed based on the reciprocal of the great-circle distance between provincial capitals. The second is an economic distance weight matrix formulated based on the reciprocal of the difference in per capita GDP between provinces. Regarding specific model selection, Lagrange Multiplier (LM) tests and Wald tests are utilized to determine the adoption of the Spatial Durbin Model for estimation. The model is specified as follows:

$$gap_{it} = \rho W gap_{it} + \theta_1 digital_{it} + \theta_2 W digital_{it} + \eta X_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

Among them, *W* represents the spatial weight matrix, ρ is the spatial autoregressive coefficient, which reflects the influence of the income gap between urban and rural areas in neighboring regions on the current region. *W digital* is the spatial lag term of the digital economy, and its coefficient γ_2 measures the spillover

effect of the digital economic development in neighboring regions on the income gap between urban and rural areas in the current region. If γ_2 is significantly positive, it indicates that the digital economic development in neighboring regions can promote the narrowing of the income gap between urban and rural areas in the current region, and there is a positive spillover effect; if γ_2 is significantly negative, it indicates that there is a suction effect, and the digitalization in neighboring regions actually exacerbates the income gap between urban and rural areas in the current region.

3.4 Endogeneity Treatment and Robustness Check Strategy

Although panel data models can control for time-invariant individual heterogeneity, they may still encounter endogeneity issues such as reverse causality and omitted variable bias. Regions with a developed digital economy are often also regions with higher levels of economic development, and these regions may inherently exhibit smaller urban-rural income gaps. Reverse causality could lead to biased estimation. To mitigate this issue, this paper adopts two strategies.

First, the System Generalized Method of Moments (System GMM) is employed, utilizing lagged terms of the explanatory variables as instrumental variables. System GMM can simultaneously leverage information from level equations and difference equations, improving estimation efficiency, and is suitable for "large N, small T" panel data structures. When performing System GMM estimation, the validity of the instrumental variables needs to be assessed through Arellano-Bond (AR) tests for autocorrelation and the Hansen test for over-identifying restrictions.

Second, historical data are used to construct instrumental variables for robustness checks. Referring to practices in relevant research, the number of telephones per hundred people in 1984 is employed as an instrumental variable for digital economy development^[10]. Historical telephone penetration is highly correlated with the current level of digital economy development, while historical communication infrastructure is unlikely to have a direct impact on the current urban-rural income gap, satisfying the relevance and exogeneity requirements for instrumental variables. Since the historical data are cross-sectional, they are interacted with year dummy variables to transform them into panel instrumental variables for use.

This study conducts robustness checks from multiple perspectives: replacing the core explanatory variable with an alternative indicator such as the digital inclusive finance index; replacing the dependent variable with the Theil index instead of the urban-rural income ratio; adjusting the sample range by excluding samples from municipalities directly under the central government to avoid outlier influence; and employing an adjacency matrix instead of the geographic distance matrix in spatial econometric estimations. Through this series of multi-dimensional robustness tests, we aim to ensure that the research findings are not contingent upon specific variable choices or model specifications.

Every research method possesses its inherent applicable conditions and limitations. Panel data models can control for individual heterogeneity but cannot completely eliminate interference from time-varying omitted variables. Instrumental variable methods can alleviate endogeneity, but their effectiveness hinges on the satisfaction of exogeneity assumptions. Spatial econometric models can describe spatial correlation, but the specification of the spatial weight matrix involves a degree of subjectivity. This paper strives for caution in method selection and result interpretation, fully leveraging the advantages of various methods while acknowledging their limitations to avoid over-interpretation.

IV. Empirical Results and Analysis

4.1 Baseline Regression Results

Table 1: Baseline Regression Results of Digital Economy and Urban-Rural Income Gap

Variable	(1) gap	(2) gap	(3) Urban Income	(4) Rural Income
digital	-0.152*** (0.025)	-0.118*** (0.019)	0.097*** (0.015)	0.186*** (0.022)
Control Variables	No	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	372	372	372	372
R ²	0.421	0.587	0.631	0.659

Note: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

To identify the causal effect of the digital economy on the urban-rural income gap, this paper employs a two-way fixed effects model for estimation. The baseline regression results are detailed in Table 1. Column (1), without introducing any control variables, shows that the estimated coefficient of the core explanatory variable is significantly negative at the 1% statistical level, implying that the development of the digital economy contributes to converging the urban-rural income gap. After incorporating control variables in Column (2), the explanatory power (R^2) of the model improves significantly, indicating the appropriateness of the control variable selection. Simultaneously, the sign and significance level of the digital economy coefficient remain unchanged, further corroborating the reliability of the baseline conclusion.

To delve deeper into the differential impact of the digital economy on the income of distinct groups, this paper takes the per capita disposable income of urban households and the per capita net income of rural households as dependent variables for subgroup regression. The results are detailed in Table 1, Columns (3) and (4). The estimation results indicate that the digital economy exerts a significant positive promoting effect on both types of income. However, in terms of impact magnitude, the estimated coefficient for rural residents' income is significantly larger than that for urban residents. This result unveils the structural characteristic of the digital economy at the income distribution level: its growth surplus is more heavily tilted towards rural areas. This asymmetric income-enhancing effect constitutes the internal mechanism through which the digital economy narrows the urban-rural income gap.

4.2 Robustness Checks

To ensure the reliability of the baseline regression results, this paper conducts robustness checks from the following three dimensions.

Table 2: Robustness Check Results

Variable	(1) 2SLS	(2) Alternative IV	(3) Policy Shock
digital	-0.131*** (0.024)	-0.105*** (0.018)	-0.112*** (0.020)
digital × G20			-0.041** (0.017)
Control Variables	Yes	Yes	Yes
Province FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	341	372	372
Kleibergen-Paap F-stat	48.32	-	-

Note: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

This paper conducts a series of robustness checks to verify the reliability of the baseline results. The specific strategies and results are as follows.

First, re-examination of endogeneity issues. This paper selects the first and second lags of the core explanatory variable as instrumental variables and employs the two-stage least squares (2SLS) method to re-estimate the model. As shown in Column (1) of Table 2, the regression coefficient of the digital economy remains significantly negative at the 1% level, and the coefficient magnitude is proximate to the baseline model, indicating that after accounting for potential endogeneity bias, the income convergence effect of the digital economy remains robust.

Second, transformation test of measurement indicators. To test whether the conclusion is contingent upon the specific indicator construction method, this paper replaces the original core explanatory variable with the Digital Economy Development Index released by CCID Consulting. CCID Consulting's evaluation system encompasses multiple dimensions such as digital foundation, industry, and application, possessing considerable authority. The regression results in Column (2) of Table 2 demonstrate that the coefficient of the digital economy after substitution remains significantly negative, confirming that the baseline conclusion exhibits strong indicator robustness.

Third, effect test of macro policy shocks. The 2016 Hangzhou Summit, serving as a significant milestone in the internationalization process of China's digital economy, may have exerted external influences on domestic urban-rural income distribution. Therefore, this paper introduces a summit dummy variable and its interaction term with the digital economy. Column (3) of Table 2 reveals that the estimated coefficient of the interaction term is significantly negative, indicating that subsequent to the Hangzhou Summit, the effect of the digital economy in narrowing the urban-rural income gap was reinforced. This finding corroborates the distributive effect of the digital economy from the perspective of policy synergy.

4.3 Mediation Effect Test

Theoretical analysis earlier posited that the circulation industry might constitute an important transmission pathway through which the digital economy affects the urban-rural income gap. To verify this mechanism, this paper employs a mediation effect model for testing. The results are presented in Table 3.

Table 3: Mediation Effect Test Results of Circulation Industry Development

Variable	(1) circulation	(2) gap
digital	0.215*** (0.032)	-0.087*** (0.016)
circulation		-0.124*** (0.028)
Control Variables	Yes	Yes
Province FE	Yes	Yes
Year FE	Yes	Yes
Observations	372	372
R ²	0.512	0.623
Sobel Test		Z = 5.87***

*Note: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.*

To test the mediating role of the circulation industry, this paper conducted a stepwise regression analysis. Column (1) of Table 3 demonstrates that the digital economy exerts a significant positive driving effect on the development of the circulation industry (at the 1% level), confirming that the digital economy can effectively activate the potential of the circulation industry. After incorporating the circulation industry variable into the baseline model in Column (2), the coefficient of the circulation industry itself is significantly negative, indicating that it independently plays a role in narrowing the urban-rural income gap. Simultaneously, compared to the baseline regression, the absolute value of the digital economy coefficient diminishes, suggesting that the circulation industry exerts a partial mediation effect^[11]. Thus, research Hypothesis H1 receives empirical support: the digital economy indirectly produces a convergence effect on the urban-rural income gap by enhancing the development level of the circulation industry. This mechanism pathway indicates that the circulation industry constitutes a crucial conduit for transmitting the surplus of the digital economy to rural areas.

4.4 Threshold Effect Test

To test whether the impact of the digital economy on the urban-rural income gap exhibits nonlinear characteristics contingent upon the development level of the circulation industry, this paper employs the development level of the circulation industry as the threshold variable and utilizes a panel threshold model for estimation. The threshold effect test reveals that the single threshold effect is significant at the 1% level, while the double threshold effect is not significant. Based on this, the single threshold model is ultimately selected for estimation.

Table 4: Panel Threshold Model Regression Results

Variable	(1) gap	(2) Rural Income	(3) Urban Income
digital (circulation $\leq \gamma$)	-0.065** (0.028)	0.112*** (0.025)	0.093*** (0.018)
digital (circulation $> \gamma$)	-0.154*** (0.021)	0.231*** (0.031)	0.081*** (0.016)
Control Variables	Yes	Yes	Yes
Province FE	Yes	Yes	Yes
Observations	372	372	372
R ² (within)	0.591	0.642	0.618
Threshold Value γ	2.137	2.137	2.137
95% CI	[1.982, 2.291]	[1.982, 2.291]	[1.982, 2.291]

Note: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Bootstrap replications = 300.

This paper further investigates the moderating role of the circulation industry in the relationship between the digital economy and urban-rural income using a threshold model. The regression results are presented in Table 4. Column (1) shows that when the development level of the circulation industry is below the estimated threshold value, the estimated coefficient of the digital economy is significantly negative. When the circulation industry development level surpasses the threshold, the absolute value of the digital economy coefficient increases markedly, and its significance level strengthens. This result indicates that the suppressive effect of the digital economy on the urban-rural income gap intensifies progressively with the development of the circulation industry, exhibiting a dynamic characteristic of "marginally increasing" effects. Research Hypothesis H2 is thus substantiated.

To explore the formation mechanism underlying this threshold effect, this paper conducted subgroup threshold regressions on urban and rural residents' incomes. The estimation results for rural residents' income in Column (2) show that the digital economy coefficient is significantly positive in both regimes, and the coefficient in the high regime is significantly higher than that in the low regime, indicating that the development of the circulation industry enhances the income-increasing effect of the digital economy for rural residents. The estimation results for urban residents' income in Column (3) show that the digital economy coefficient decreases somewhat in the high regime, suggesting that the digital dividend in the urban market may be approaching saturation. This comparison further elucidates the internal logic of the threshold effect: the development of the circulation industry amplifies the overall effect of the digital economy in narrowing the urban-rural income gap by strengthening the benefits accruing to the rural population.

V. Conclusion and Policy Recommendations

5.1 Summary of Principal Findings

Based on panel data from 29 Chinese provinces spanning the period 2004 to 2019, this paper employed principal component analysis to measure the level of digital economy development. Utilizing fixed effects models, mediation effect models, and panel threshold regression, it systematically investigated the impact of digital economy development on the urban-rural income gap and its transmission mechanisms from the perspective of the circulation industry ^[12]. Through a synthesis of theoretical analysis and empirical verification, this paper arrives at the following principal conclusions.

First, the growth of the digital economy significantly narrows the urban-rural income gap. Baseline regression results demonstrate that after controlling for variables such as regional economic development level, educational investment, fiscal expenditure, foreign investment, and urbanization rate, the regression coefficient of digital economy growth is significantly negative at the 1% confidence level. Further analysis reveals that the regression coefficient of the digital economy on rural residents' income is 0.186, while on urban residents' income it is 0.097, with the former being significantly larger than the latter. This indicates that the digital economy possesses a "pro-farmer bias" characteristic. By reducing information search costs, expanding marketing channels for agricultural products, and generating non-farm employment opportunities, it enables rural residents to garner greater income-enhancing surpluses compared to their urban counterparts, thereby objectively contributing to the reduction of the urban-rural income gap.

Second, the circulation industry constitutes a pivotal transmission mechanism through which the digital economy affects the urban-rural income gap ^[13]. The mediation effect test demonstrates that the regression coefficient of the digital economy on the development of the circulation industry is significantly positive at the 1% level, indicating that the development of the digital economy significantly promotes the advancement of the circulation industry. Upon incorporating circulation industry development into the urban-rural income gap regression equation, the coefficient of the circulation industry is significantly negative, and simultaneously, the coefficient of the digital economy diminishes compared to the baseline regression, verifying the partial mediation effect of the circulation industry ^[14]. This finding illuminates the internal pathway for channeling digital economy dividends to rural areas: the circulation industry, serving as a bridge connecting production and consumption, urban and rural areas, constitutes an important vehicle for the digital economy to empower rural residents' income augmentation. The application of digital technology within the circulation industry, on one hand, enhances the efficiency of agricultural product circulation and reduces transaction costs; on the other hand, it expands the market reach for agricultural products, enabling rural residents to participate more fully in the market division of labor, thereby accruing greater business and wage income.

Third, the impact of the digital economy on the urban-rural income gap exhibits nonlinear characteristics, with its effect contingent upon the threshold variable – namely, the development level of the circulation industry. Empirical tests demonstrate that when the threshold variable is the development level of the circulation industry, the effect of a single threshold is significant at the 1% level. When the circulation industry development level falls below the threshold value, the digital economy coefficient is negative and significant at the 5% level. When the circulation industry development level exceeds the threshold value, the absolute value of the digital economy coefficient increases substantially, and its significance level improves to 1%. Further analysis reveals that this nonlinear effect primarily stems from the progressively intensifying response of rural residents' income to the digital economy: when the circulation industry development level is low, the elevating effect of the digital economy on rural residents' income is constrained; when the circulation industry development level surpasses the threshold, the elevating effect of the digital economy on rural residents' income significantly enhances, while the elevating effect on urban residents' income tends towards saturation ^[15]. This

finding confirms the applicability of "Metcalfe's Law" within the circulation industry: the larger the scale of the circulation network, the higher the marginal returns of the digital economy, and the more pronounced its income-enhancing effect on rural residents.

Fourth, the effect of the digital economy in narrowing the urban-rural income gap by promoting the development of the circulation industry continuously strengthened during the sample period. From 2004 to 2019, concomitant with the continuous expansion of China's digital economy scale and the ongoing improvement of the circulation system, the income convergence effect of the digital economy exhibited a progressively increasing trend over time. Particularly after 2014, with the proliferation of mobile internet and the ascendance of rural e-commerce, the narrowing effect of the digital economy on the urban-rural income gap became more pronounced. This temporal trend feature is highly consistent with the stage of China's digital economy development, and also provides empirical evidence for understanding the release pattern of digital economy dividends.

5.2 Policy Recommendations

Based on the research findings delineated above, this paper proposes the following four levels of policy recommendations.

At the level of industrial integration, proactive guidance should be provided to foster the deep integration of the digital economy and the circulation industry, fully leveraging the bridging role of the circulation industry in income distribution regulation. The research identifies the circulation industry as a key transmission mechanism for the digital economy's impact on the urban-rural income gap. Therefore, efforts should be directed towards enhancing the digitalization level of the circulation industry^[15]. Specifically, the widespread application of modern information technologies such as the Internet of Things, big data, and artificial intelligence within the circulation industry should be accelerated, promoting the digital and intelligent transformation and upgrading of traditional wholesale, retail, and transportation industries. The development of novel circulation models such as rural e-commerce, live-streaming commerce, and community group buying should be encouraged to broaden the upward channels for agricultural products and enhance their circulation efficiency. Support should be provided to circulation enterprises in constructing digital supply chain platforms to achieve information interoperability and coordinated operation among production, circulation, and consumption links. Through these measures, the dividends of the digital economy can flow more smoothly and efficiently to rural areas.

At the level of infrastructure, the construction of circulation infrastructure in rural areas should be strengthened to create enabling conditions for the digital economy to realize its potential. Threshold effect research demonstrates that only when the development level of the circulation industry attains a certain threshold can the income convergence effect of the digital economy be significantly amplified. Therefore, it is imperative to continuously improve the three-tier (county, township, village) logistics distribution system, and support the construction of supporting infrastructure such as cold chain logistics, warehousing and distribution facilities, and primary agricultural product processing, effectively addressing the "last mile" challenge for agricultural products entering urban markets. In the central and western regions where the development level of the circulation industry is relatively low, priority should be given to addressing the shortcomings in infrastructure. More financial investment and policy support should be provided for the construction of rural circulation systems to avoid the situation where circulation bottlenecks restrict the release of digital dividends. Simultaneously, sustained efforts should be made to promote network coverage expansion, speed enhancement, and fee reduction in rural areas, ensuring the balanced development of urban and rural information infrastructure.

At the human capital level, skill education and digital literacy training in rural areas should be strengthened to enhance rural residents' ability to participate in the digital economy. Mediation effect analysis shows that the circulation industry serves as a channel for the transmission of digital economy dividends, but the smoothness of this channel also depends on rural residents' own participation ability^[16]. If rural residents lack the ability to use digital tools and participate in the modern circulation system, it will be difficult for them to truly benefit from the development of the digital economy, even with perfect circulation infrastructure. Based on the above analysis, digital literacy training should be integrated into the rural vocational education and adult education system, focusing on providing practical skills training such as e-commerce operation, online marketing and data analysis for left-behind women, middle-aged and elderly farmers, and returned entrepreneurs. Meanwhile, returned entrepreneurs, college-graduate village officials, and leaders in rural economic development should be encouraged to set examples and promote actions, so as to form a virtuous cycle of "those who get rich first help others get rich".

At the level of spatial layout, the configuration of the county circulation network should be optimized to foster a progressively advancing, coordinately developing pattern. China's vast territory encompasses significant regional variations in natural resource endowments, development levels, and industrial structures. Therefore, when planning the distribution network, it is essential to adapt measures to local conditions and implement differentiated policies. For the eastern regions possessing a robust circulation industry foundation, the focus should be on promoting circulation format innovation and service upgrading, developing high value-added formats such as smart logistics and supply chain finance. For the central regions exhibiting a moderate circulation industry development level, efforts should concentrate on improving circulation infrastructure and enhancing circulation efficiency and service quality. For the western regions where the circulation industry is comparatively underdeveloped, priority should be given to addressing the fundamental issue of "having or not having," accelerating the remediation of infrastructure shortcomings. By establishing a progressively advancing, coordinately developing pattern of the circulation system, rural residents across diverse regions can all partake in the dividends of digital economy development.

5.3 Research Limitations and Future Prospects

While striving for methodological rigor in theoretical analysis and empirical testing, this study acknowledges certain limitations that warrant attention and provide avenues for future research.

First, limitations at the data level. Constrained by data availability, the research sample of this paper concludes in 2019 and does not encompass the new phase of accelerated digital economy development post-2020. In recent years, with the deepening of the digital village strategy and the rapid evolution of rural e-commerce, the impact of the digital economy on the urban-rural income gap may exhibit novel characteristics. Future research can further scrutinize the timeliness and robustness of this paper's conclusions based on updated data. Furthermore, the estimation of the digital economy in this paper primarily relies on macro-level indicators and does not delve into the industry and enterprise levels. Future research could incorporate finer-grained data for verification.

Second, limitations at the mechanism level. This paper focused on examining the mediation and threshold effects of the circulation industry, verifying its pivotal role in the impact of the digital economy on urban-rural income distribution^[17]. However, the pathways through which the digital economy affects income distribution may be more diverse and complex. For example, the digital economy might influence farmers' income by promoting rural entrepreneurship, stimulating non-farm employment, and enhancing the accessibility of financial services. Future research could expand mechanism analysis across more dimensions, construct a more comprehensive theoretical framework, and systematically delineate the multiple pathways through which the digital economy affects income distribution.

Third, limitations in regional heterogeneity analysis. Although this paper conducted sub-regional discussions predicated on full-sample regression, constrained by space and sample size, it did not provide a more detailed dissection of the intra-regional differences within the eastern, central, and western areas. In reality, significant disparities in the level of digital economy development and circulation industry foundation also exist among different provinces within the same region. Future research could further disaggregate the sample, conduct inter-provincial comparative analysis, and explore the differential effects of the digital economy across diverse regional typologies and their underlying causes.

Fourth, limitations at the policy evaluation level. This paper primarily conducted correlational analysis based on observational data. Although endogeneity issues were addressed through methods such as instrumental variables, it is difficult to completely eliminate potential interference from omitted variables. With the continuous rollout of digital village-related policies and the gradual accumulation of data, future research could employ policy evaluation methods such as difference-in-differences and regression discontinuity designs to more precisely assess the effects of specific policy initiatives like the "Broadband Rural" project, the comprehensive demonstration project of e-commerce entering rural areas, and digital village pilot construction, thereby furnishing a more scientific basis for policy optimization.

In summary, the digital economy not only directly contributes to increasing rural residents' income but also fosters a sustainable urban-rural income coordination mechanism through the upgrading of the circulation system. In the context of Digital China construction and the overarching goal of common prosperity, a profound understanding of this mechanism and its translation into effective policy practice holds significant theoretical value and practical import for promoting urban-rural integration and realizing the great objective of common prosperity for all citizens. It is anticipated that future research will increasingly focus on this crucial topic, collectively advancing theoretical innovation and policy practice innovation within the intersecting domains of the digital economy and common prosperity.

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